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(54) **VERTICAL-TYPE HEAT TREATMENT APPARATUS**

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**F27B 17/00** (2006.01)

**H01L 21/67** (2006.01)

(52) **U.S. Cl.**

CPC ..... **F27B 17/0025** (2013.01); **H01L 21/67109** (2013.01); **H01L 21/67248** (2013.01)

(58) **Field of Classification Search**

CPC ..... F27B 17/0025

USPC ..... 432/42, 48, 95, 247, 49

See application file for complete search history.

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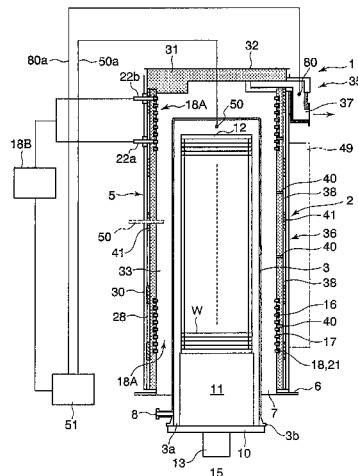
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(57)

#### ABSTRACT

A heat treatment apparatus and control method enabling the apparatus to settle down an internal temperature of a treating vessel to a target temperature accurately and quickly. The heat treatment apparatus includes a furnace body with a heater on an inner circumferential surface thereof, the treating vessel disposed inside the furnace body, a cooling medium supply blower and cooling medium release blower each connected to the furnace body, and a temperature sensor provided inside the treating vessel. A signal from the temperature sensor is sent to a heater output computing unit and blower output computing unit included in a controller. The heater output computing unit determines a heater output level based on a heater output numerical model and the signal from the temperature sensor. The blower output computing unit determines a blower output level based on a blower output numerical model and the signal from the temperature sensor.

**8 Claims, 6 Drawing Sheets**



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FIG. 1

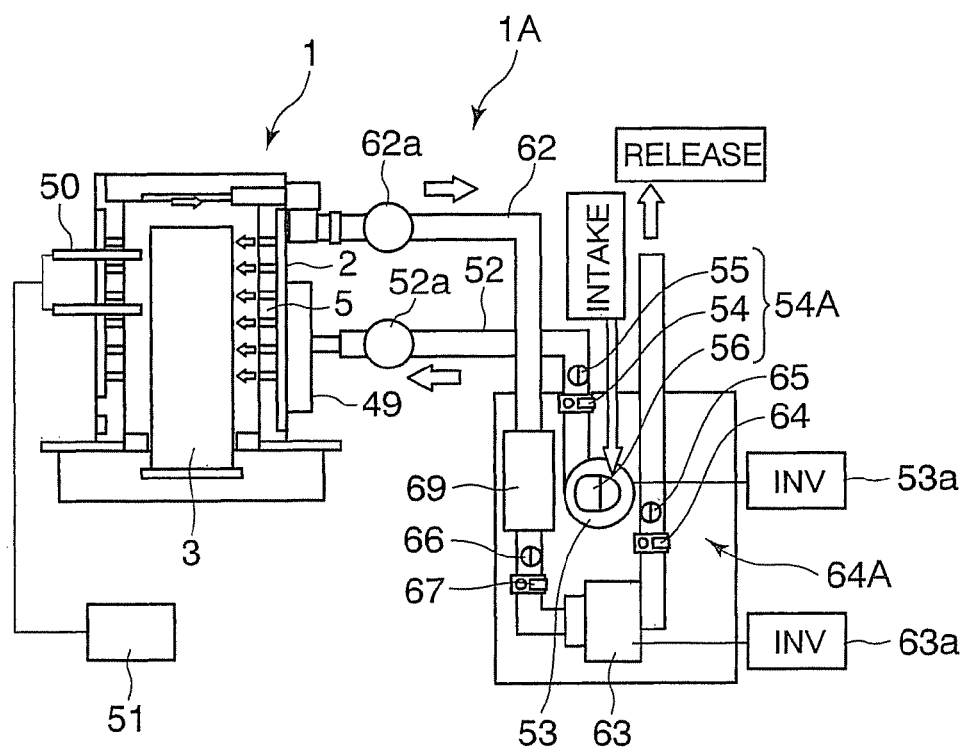


FIG. 2

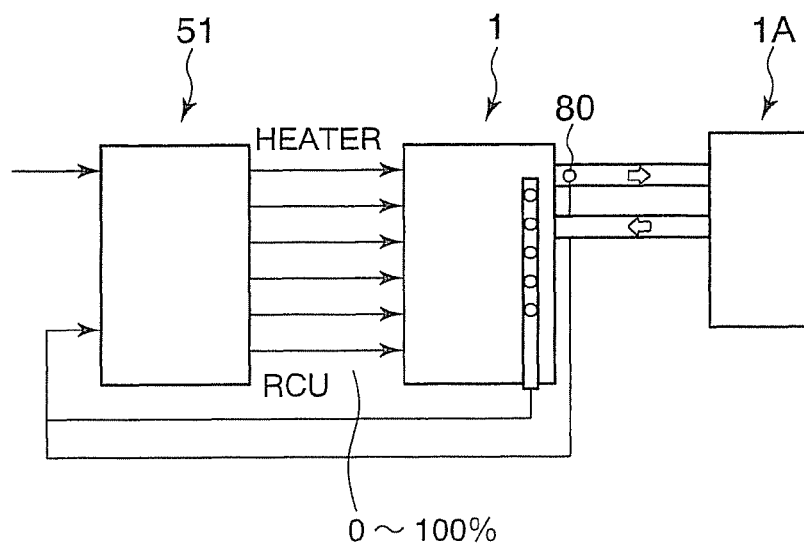


FIG. 3

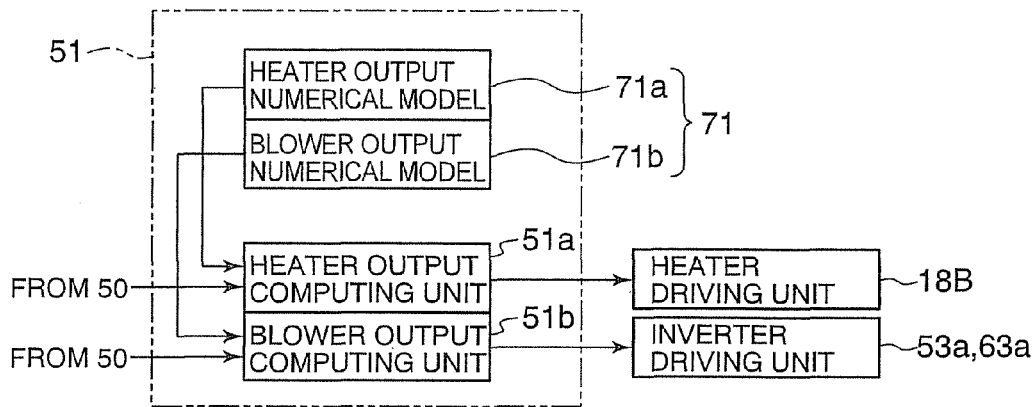


FIG. 4

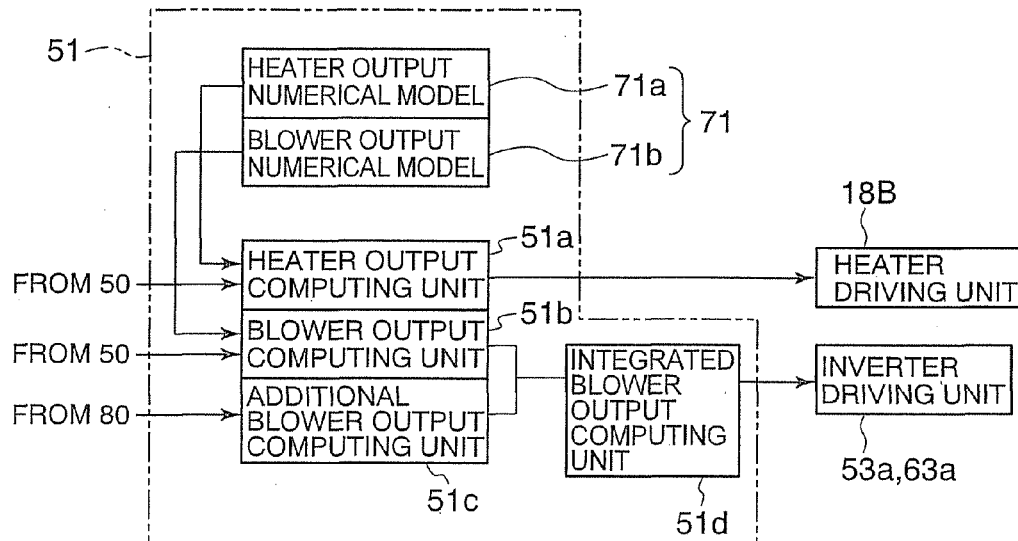


FIG. 5

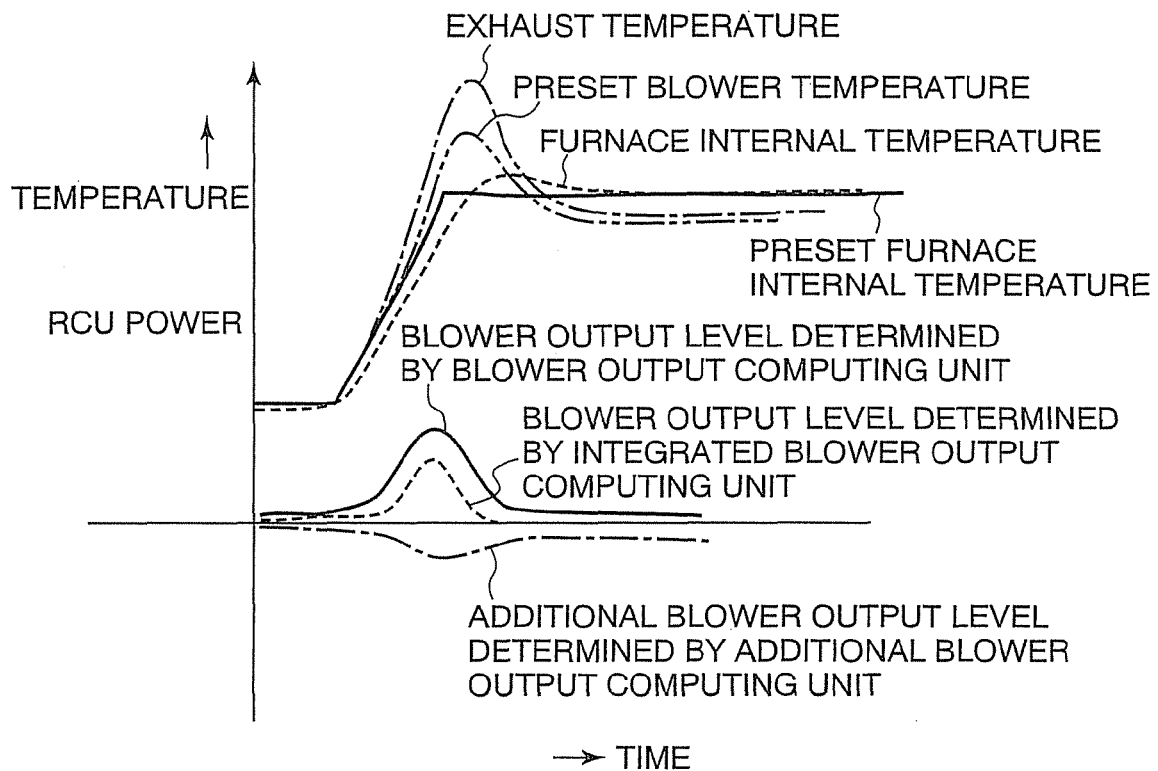


FIG. 6

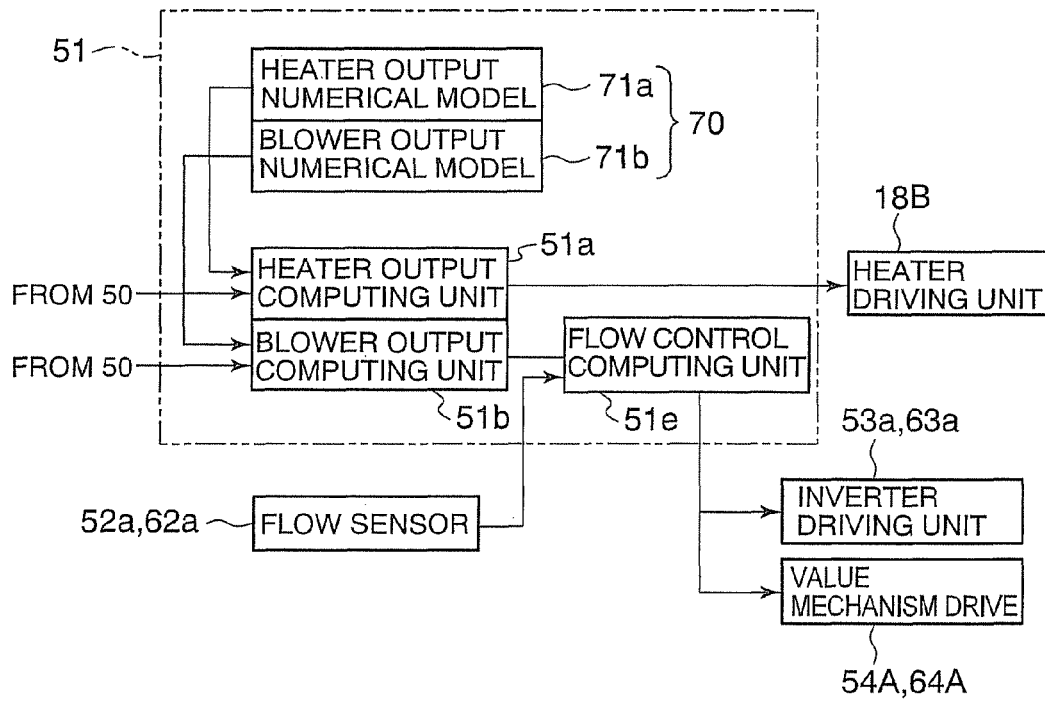


FIG. 7

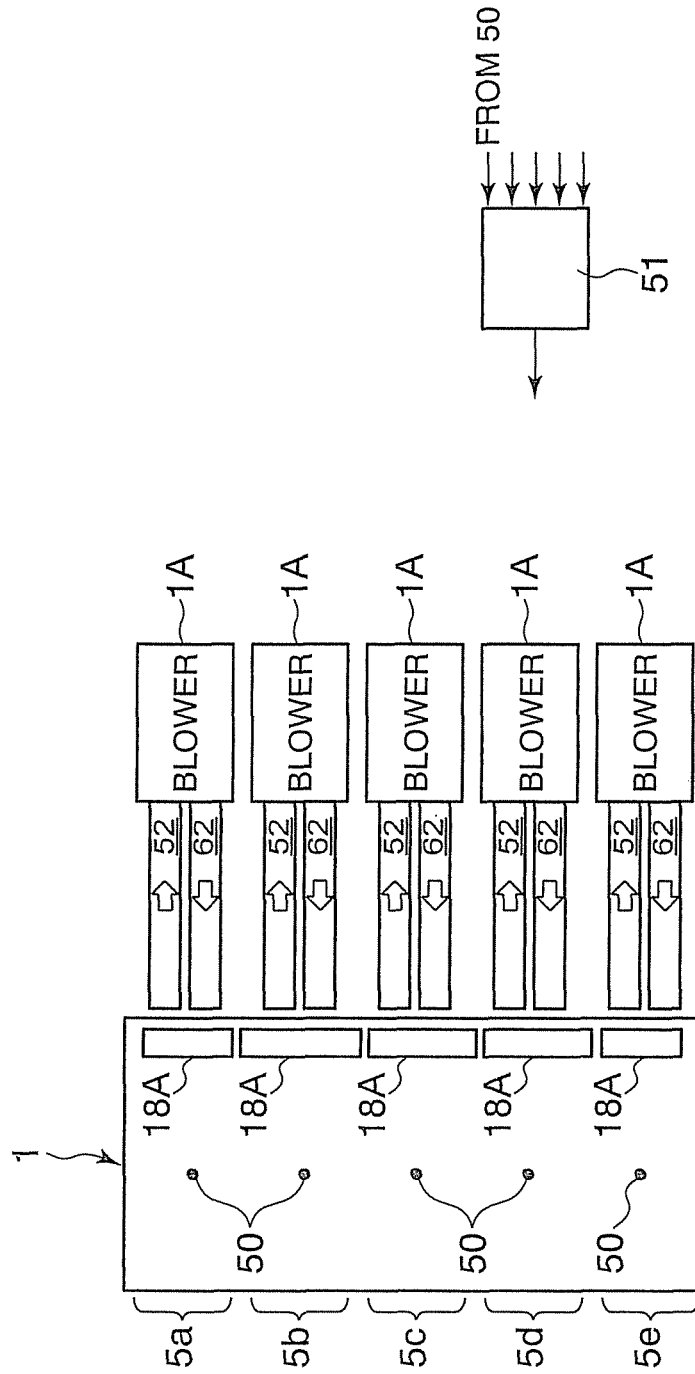


FIG. 8



# VERTICAL-TYPE HEAT TREATMENT APPARATUS

## CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application benefits from Japanese Patent Application No. 2010-201821, filed on Sep. 9, 2010, the disclosure of which is hereby incorporated by reference in its entirety.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to a vertical-type heat treatment apparatus.

### 2. Description of the Related Art

During the manufacture of semiconductor devices, various types of heat treatment apparatuses are used to conduct oxidizing, diffusing, chemical vapor deposition (CVD), annealing, and/or other heat treatment processes, upon materials to be heat-treated, such as semiconductor wafers. Among these apparatuses is known a vertical-type heat treatment apparatus capable of heat-treating a large number of sheets at a time. This conventional vertical-type heat treatment apparatus includes a quartz-made treating vessel having an opening in its lower portion, a lid for blocking/unblocking the opening in the treating vessel, a holder provided on the lid, for holding in a vertical direction at predetermined spatial intervals, a plurality of objects to be processed, and a furnace body surrounding the treating vessel and including a heater to heat the target materials after loading of the materials into the treating vessel.

JP-A-2002-305189, for example, proposes another vertical-type heat treatment apparatus, which is equipped with an air blower to forcibly air-cool a treating vessel by supplying air to the inside of a furnace body including a heater. The blower has been used for rapidly cooling wafers and the treating vessel after heat treatment.

Heat treatment processes include heat-treating wafers in a low-temperature region of, for example, 100 to 500° C., for a purpose such as forming a layer of a low dielectric constant. During the heat treatment in the low-temperature region, it becomes important how fast the furnace interior can be heated up or cooled down to a predetermined heat-treating temperature. An existing heat-treatment apparatus proposed for low-temperature applications includes a metallic treating chamber, not a quartz-made treating vessel, to obtain faster thermal response. However, if reaction products, by-products, or other substances are likely to stick to the furnace interior during the heat treatment, the use of a quartz-made treating vessel easier to clean and replace than a metallic treating chamber is necessary for reasons associated with the apparatus configuration. Additionally, although energy saving in the apparatus is achievable by using a heater having high heat-insulating performance, the use of the heater deteriorates the furnace in the controllability of internal temperature. In this case, it also becomes important how fast the furnace interior can be heated up or cooled down to a predetermined heat-treating temperature, and this issue also applies to temperatures other than those of the low-temperature region discussed above.

## RELATED DOCUMENTS

Document 1: JP-A-2002-305189

Document 2: JP-A-2005-188869

# SUMMARY OF THE INVENTION

The vertical-type heat treatment apparatus with a quartz-made treating vessel, however, has had a problem in that the settling time required for the furnace interior to recover from the heated state in the low-temperature region and settle down to a desired temperature tends to increase since the treating vessel has a large heat capacity. The same problem due to using a highly adiabatic heater for purposes such as energy saving, also occurs in temperature regions other than low-temperature regions. The above-discussed increase in settling time during the recovery from the heated state is influential upon the improvement of throughput. The problem of the increase in settling time occurs not only in the heating process, but also in a cooling process or under temperature stability.

The present invention has been made with the above problem taken into account, and an object of the invention is to provide a heat treatment apparatus and a method for controlling the apparatus, the apparatus being able to reduce a settling time required in a heating or cooling phase or stable temperature state during use of a heater in a low-temperature region or having high heat-insulating performance, and to settle down an internal temperature of a treating vessel to a target temperature very accurately.

A heat treatment apparatus according to a first aspect of the present invention includes: a furnace body; a heater provided on an inner circumferential surface of the furnace body; a treating vessel disposed inside the furnace body, the treating vessel forming a space between the furnace body and the vessel and internally accommodating a plurality of objects to be processed; a blower, connected to the furnace body via a cooling medium supply line, for supplying a cooling medium to the space formed between the furnace body and the treating vessel; an exhaust pipe connected to the furnace body; a furnace temperature sensor that detects internal temperature or external temperature of the treating vessel; and a controller that regulates the internal temperature of the treating vessel by controlling the heater and the blower in order to settle down the internal temperature of the treating vessel to a predetermined target temperature, wherein the controller includes: a numerical model relating to predetermined heater output and blower output levels; a heater output computing unit that determines a heater output level based on the numerical model and the furnace internal temperature detected by the furnace temperature sensor; and a blower output computing unit that determines a blower output level based on the numerical model and the furnace internal temperature detected by the furnace temperature sensor.

In the heat treatment apparatus according to the first aspect, the numerical model includes a heater output numerical model and a blower output numerical model, the heater output computing unit determines a heater output level based on the heater output numerical model and the furnace internal temperature from the furnace temperature sensor, and the blower output computing unit determines a blower output level based on the blower output numerical model and the furnace internal temperature from the furnace temperature sensor.

In the heat treatment apparatus according to the first aspect, the controller further includes a flow control computing unit that converts the blower output level, computed by the blower output computing unit, into a flow rate of the cooling medium.

In the heat treatment apparatus according to the first aspect, the flow control computing unit controls a rotating speed of the blower, based on the flow rate of the cooling medium.

In the heat treatment apparatus according to the first aspect, the exhaust pipe is provided with an exhaust temperature sensor, and the controller further includes an additional blower output computing unit that determines an additional blower output level appropriate for a preset temperature which follows the exhaust temperature from the exhaust temperature sensor, and an integrated blower output computing unit that combines the blower output level from the blower output computing unit and the additional blower output level from the additional blower output computing unit.

A heat treatment apparatus according to a second aspect of the present invention includes: a furnace body partitioned into a plurality of zones; heaters each provided on an inner circumferential surface of each zone of the furnace body; a treating vessel disposed inside the furnace body, the treating vessel forming a space between the furnace body and the vessel and internally accommodating a plurality of objects to be processed; blowers, each connected to each zone of the furnace body via a cooling medium supply line, for supplying a cooling medium to the space formed between the furnace body and the treating vessel; exhaust pipes each connected to each zone of the furnace body; furnace temperature sensors each provided at a position associated with each zone of the furnace body, each sensor detecting internal temperature or external temperature of the treating vessel; and a controller that regulates the internal temperature of the treating vessel by controlling the corresponding heater and blower for each zone of the furnace body in order to settle down the internal temperature of the treating vessel to a predetermined target temperature, wherein the controller includes: a numerical model for each zone of the furnace body, each numerical model relating to predetermined heater output and blower output levels; a heater output computing unit that determines a heater output level for each zone, based on the numerical model corresponding to the particular zone and the furnace internal temperature detected by the corresponding furnace temperature sensor; and a blower output computing unit that determines a blower output level in a particular zone, based on the numerical model corresponding to the particular zone and the furnace internal temperature detected by the corresponding furnace temperature sensor.

A heat treatment apparatus according to a third aspect of the present invention includes: a furnace body; a heater provided on an inner circumferential surface of the furnace body; a treating vessel disposed inside the furnace body, the treating vessel forming a space between the furnace body and the vessel and internally accommodating a plurality of objects to be processed; a blower, connected to the furnace body via a cooling medium supply line, for supplying a cooling medium to the space formed between the furnace body and the treating vessel; a valve mechanism that regulates a flow rate of the cooling medium supplied from the blower; an exhaust pipe connected to the furnace body; a furnace temperature sensor that detects internal temperature or external temperature of the treating vessel; and a controller that regulates the internal temperature of the treating vessel by controlling the heater and the valve mechanism in order to settle down the internal temperature of the treating vessel to a predetermined target temperature; wherein the controller includes: a numerical model relating to predetermined heater output and cooling output levels; a heater output computing unit that determines a heater output level based on the numerical model and the furnace internal temperature detected by the furnace temperature sensor; a cooling output computing unit that determines a cooling output level based on the numerical model and the furnace internal temperature detected by the furnace temperature sensor; and a flow control computing unit that converts

the cooling output level determined by the cooling output computing unit, into the flow rate of the cooling medium, the flow control computing unit controlling the valve mechanism in accordance with the cooling medium flow rate.

In the heat treatment apparatus according to the third aspect, the numerical model includes a heater output numerical model and a cooling output numerical model, the heater output computing unit determines a heater output level based on the heater output numerical model and the furnace internal temperature from the furnace temperature sensor, and the cooling output computing unit determines a cooling output level based on the cooling output numerical model and the furnace internal temperature from the furnace temperature sensor.

A heat treatment apparatus according to a fourth aspect of the present invention includes: a furnace body partitioned into a plurality of zones; heaters each provided on an inner circumferential surface of each zone of the furnace body; a treating vessel disposed inside the furnace body, the treating vessel forming a space between the furnace body and the vessel and internally accommodating a plurality of objects to be processed; blowers, each connected to each zone of the furnace body via a cooling medium supply line, for supplying a cooling medium to the space formed between the furnace body and the treating vessel; a valve mechanism that regulates a flow rate of the cooling medium supplied from each blower; exhaust pipes each connected to each zone of the furnace body; furnace temperature sensors each provided at a position associated with each zone of the furnace body, each sensor detecting internal temperature or external temperature of the treating vessel; and a controller that regulates the internal temperature of the treating vessel by controlling the corresponding heater and valve mechanism for each zone of the furnace in order to settle down the internal temperature of the treating vessel to a predetermined target temperature, wherein the controller includes: a numerical model for each zone of the furnace body, each numerical model relating to predetermined heater output and cooling output levels; a heater output computing unit that determines a heater output level for each zone, based on the numerical model corresponding to the particular zone and the furnace internal temperature detected by the corresponding furnace temperature sensor; a cooling output computing unit for each zone that determines a cooling output level in a particular zone, based on the numerical model corresponding to the particular zone and the furnace internal temperature detected by the corresponding furnace temperature sensor; and a flow control computing unit that converts the cooling output level determined by the cooling output computing unit, into the flow rate of the cooling medium, the flow control computing unit controlling the valve mechanism corresponding to the particular zone in accordance with the cooling medium flow rate.

The present invention can reduce a cooling-down time during the heating phase, cooling phase, or stabilized temperature state in a low-temperature range, settle down the internal temperature of the treating vessel to the target temperature very accurately, and thus improve throughput. Alternatively, in the present invention, when a heater having high heat-insulating performance is used, electric power consumption can be reduced without an impact upon throughput.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal cross-sectional view schematically showing a first embodiment of a heat treatment apparatus according to the present invention;

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FIG. 2 is a diagram showing a cooling medium supply line and cooling medium release line of the heat treatment apparatus;

FIG. 3 is a schematic view showing a control method for the heat treatment apparatus;

FIG. 4 is a schematic view showing a controller of the heat treatment apparatus;

FIG. 5 is a schematic view showing a controller in a second embodiment of a heat treatment apparatus;

FIG. 6, is a diagram that shows control of the heat treatment apparatus according to the second embodiment;

FIG. 7 is a schematic view showing a controller in a third embodiment of a heat treatment apparatus; and

FIG. 8 is a schematic view showing a fourth, embodiment of a heat treatment apparatus.

## DETAILED DESCRIPTION OF THE INVENTION

### First Embodiment

A first embodiment of the present invention is described below referring to part of the accompanying drawings. FIG. 1 is a longitudinal cross-sectional view schematically showing a heat treatment apparatus according to the present invention, and FIG. 2 is a diagram showing a cooling medium supply line and cooling medium release line of the heat treatment apparatus. In addition, FIG. 3 is a schematic view showing a control method for the heat treatment apparatus, and FIG. 4 is a schematic view showing a controller of the heat treatment apparatus.

The vertical type of heat treatment apparatus 1 in FIG. 1 includes a vertical type of heat treatment furnace 2 that is able to accommodate a large number of objects to be processed, for example, semiconductor wafers W, at a time and to provide each wafer W with heat treatment processes such as oxidizing, diffusing, and/or chemical vapor deposition (CVD) under reduced pressure. The heat treatment furnace 2 includes a furnace body 5 having a resistance heating element (heater) 18A on its inner circumferential surface, and a treating vessel 3 disposed inside the furnace body 5 and the treating vessel forming a space between the furnace body 5 and the vessel itself, internally accommodating the wafer W and heat-treating it. The heater 18A is formed by a plurality of heater elements 18, as described later herein.

The furnace body 5 is supported by a base plate 6, in which is formed an opening 7 for inserting the treating vessel 3 from below, in an upward direction. The opening 7 in the base plate 6 includes a heat-insulating material (not shown) for filling up or shrouding a clearance between the base plate 6 and the treating vessel 3.

The treating vessel 3, made of quartz, has a vertically elongated cylindrical shape with a blocked upper end and an opened lower end serving as an opening 3a. At the lower end of the treating vessel 3, an outward-facing flange 3b is formed, which is supported by the base plate 6 via a flange retainer not shown. An induction port 8 for inducing a process gas, an inert gas, and/or the like, into the vessel 3, and an exhaust port (not shown) for releasing the gas or gases from the treating vessel 3 are further provided on a lower section of the treating vessel 3. The induction port 8 is connected to a gas supply (not shown), and the exhaust port is connected to an exhaust system (not shown) that includes a vacuum pump having a pressure reduction control capability to obtain a vacuum pressure ranging, for example, nearly between  $133 \times 600$  Pa and  $133 \times 10^{-2}$  Pa.

Below the treating vessel 3, a lid 10 for blocking the opening 3a of the vessel 3 is provided to be vertically movable by a lift not shown. On an upper section of the lid 10, a cylindrical

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cal heat-insulating body 11 as a heat insulator for the opening is mounted, and on an upper section of the cylindrical heat-insulating body 11, a quartz-made boat 12 is mounted as a wafer retainer in which to mount a large number of, for example, about 100 to 150 wafers with a 300-mm diameter vertically at predetermined intervals. A rotating mechanism 13 that rotates the boat 12 about an axial center of the boat is provided on the lid 10. The boat 12 is unloaded from the treating vessel 3 into a loading area 15 provided below, by a downward movement of the lid 10, and after wafer transfer, the boat 12 is loaded into the treating vessel 3 by an upward movement of the lid 10.

The furnace body 5 has a cylindrical heat-insulating material 16 and a shelf 17 of a multiple-tier grooved structure formed axially (in the example of FIG. 1, vertically) on an inner circumferential surface of the heat-insulating material 16, and the heater elements (resistance heating elements) 18 are arranged along the shelf 17. The heat-insulating material 16 is formed from inorganic fibers including, for example, silica, alumina, or aluminum silicate. The heat-insulating material 16 is divided into two sections vertically, thus making it easy to mount the heater elements and to assemble the heater.

The heat-insulating material 16 has pins (not shown) holding the heater elements 18 so that the heater elements 18 is movable in a radial direction at appropriate spatial intervals and prevented from falling from or sliding out of position in the shelf 17. On the inner circumferential surface of the cylindrical heat-insulating material 16, ring-like grooves 21 concentric with the particular inner circumferential surface are formed axially in multi-tier form at predetermined pitches, and the ring-shaped shelf 17 continuous in a circumferential direction is formed between mutually adjacent upper and lower grooves 21. Clearances dimensionally sufficient to permit thermal expansion/contraction and radial movement of the heater element 18 are present between upper and lower sections of each heater element 18 in the grooves 21, a rear wall of each groove 21, and the heater element 18. These clearances also allow a cooling medium to flow around to the rear of the heater element 18 during forced cooling to effectively cool the element 18. Air, a nitrogen gas, or water is useable as the cooling medium.

Each heater element 18 is interconnected by a connecting plate, the heater elements 18 positioned in one end of the furnace 2 are further connected to an external heater-driving unit 18B via terminal strips 22a or 22b provided so as to penetrate the heat-insulating material 16 in its radial direction.

As shown in FIG. 1, the heat-insulating material 16 has an outer circumferential surface shrouded by a metallic, for example, stainless steel outer shell 28, to retain a shape of the heat-insulating material 16 in the furnace body 5 and to strengthen the heat-insulating material 16. Additionally, the outer shell 28 has an outer circumferential surface shrouded by a water-cooling jacket 30 to suppress thermal impacts upon the outside of the furnace body 5. The heat-insulating material 16 further has a top shrouded with an upper heat-insulating material 31, over which a top plate 32 made of stainless steel is further provided to shroud a top (upper end) of the outer shell 28.

As shown in FIGS. 1 and 2, in order to expedite the heat treatment or improve throughput by rapidly cooling down the wafers after the heat treatment, the furnace body 5 further includes a heat release system 35 and forced-cooling medium means 36. The heat release system 35 releases an internal atmosphere of the space 33 between the furnace body 5 and the treating vessel 3 to the outside, and the forced-cooling

medium means **36** introduces the cooling medium of a normal temperature (20 to 30° C.) into the space **33** and forcibly cools the furnace interior. The heat release system **35** includes a heat release port **37** provided, for example, at an upper section of the furnace body **5**, and a cooling medium release line **62** for releasing the cooling medium from the space **33** is connected to the heat release port **37**.

Furthermore, the forced-cooling medium means **36** includes a plurality of ring-shaped passageways **38** formed vertically between the heat-insulating material **16** and outer shell **28** of the furnace body **5**, and cooling medium blowoff holes **40** provided in the heat-insulating material **16**. The cooling medium blowoff holes **40** are constructed to blow off the cooling medium from each ring-shaped passageway **38**, in an oblique direction from a central section of the heat-insulating material **16**, and generate a swirling flow in a circumferential direction of the space **33**. The ring-shaped passageway **38** is formed by, for example, affixing a band form or ring form of heat insulator **41** to an outer circumferential surface of the heat-insulating material **16** or circularly grinding away the outer circumferential surface of the heat-insulating material **16**. The cooling medium blowoff holes **40** are formed in the shelf **17**, with each groove of the shelf sandwiched between upper and lower adjacent heater elements **18** in the heat-insulating material **16**, so as to extend through to the inside and outside of the shelf in its radial direction. In this way, the cooling medium blowoff holes **40** are provided in the shelf **17**, so the cooling medium can be jetted towards the space **33** without being obstructed by each heater element **18**.

While an example of using resistance heating elements of a band form as the heater elements **18** and accommodating these elements in the shelf **17** has been described, the heating elements **18** is not limited to the described structure and may be replaced by any one of various other heater element structures. In addition, although an example of generating a swirling flow in the space **33** by means of the cooling medium from the cooling medium blowoff holes **40** has been described, the cooling medium from the cooling medium blowoff holes **40** does not always need to be used to generate the swirling flow.

One common supply duct **49** for distributing the cooling medium to each ring-shaped passageway **38** is provided in a vertical direction along an outer circumferential surface of the outer shell **28**. Ports for establishing communication between the supply duct **49** and each ring-shaped passageway **38** are also formed in the outer shell **28**. A cooling medium supply line **52** that supplies the cooling medium is connected to the supply duct **49**.

A temperature sensor (furnace temperature sensor) **50** that detects an internal temperature of the treating vessel **3** is disposed inside the vessel **3**, and a detection signal from the temperature sensor **50** is sent to the controller **51** via a signal line **50a**. The temperature sensor **50** does not absolutely need to be provided inside the treating vessel **3** and may instead be provided inside the space **33** between the furnace body **5** and the treating vessel **3** or inside both (two-dot chain line in FIG. 1).

A temperature sensor (exhaust temperature sensor) **80** is also mounted inside the heat release port **37**, and a detection signal from the temperature sensor **80** is sent to the controller **51** via a signal line **80a**.

As shown in FIGS. 1 and 2, the cooling medium supply line **52** and the cooling medium release line **62** each constitute an open cooling medium supply/release line independently. A flow sensor **52a** and a cooling medium supply blower **53** are provided on the cooling medium supply line **52**, and the cooling medium supply blower **53** includes an inverter driving unit **53a**.

The cooling medium supply blower **53** has a damper **56** at its inlet side, and a hole valve **54** and a butterfly valve **55**, at its outlet side. The damper **56** at the inlet side of the cooling medium supply blower **53**, and the hole valve **54** and butterfly valve **55** at the outlet side are all adjustable in opening/closing angle position. The damper **56**, the hole valve **54**, and the butterfly valve **55** constitute a cooling-medium supply line valve mechanism **54A**.

A flow sensor **62a** and a cooling medium release blower **63** are provided on the cooling medium release line **62**, and the cooling medium release blower **63** includes an inverter driving unit **63a**.

The cooling medium release blower **63** has a butterfly valve **66** and a hole valve **67**, at its inlet side, and a hole valve **64** and a butterfly valve **65**, at its outlet side. The butterfly valve **66** and hole valve **67** at the inlet side of the cooling medium release blower **63**, and the hole valve **64** and butterfly valve **65** at the outlet side are all adjustable in opening/closing angle position. The butterfly valve **66**, the hole valve **67**, the hole valve **64**, and the butterfly valve **65** constitute a cooling-medium release line valve mechanism **64A**.

The cooling medium supply blower **53**, the cooling medium supply line **52**, the cooling medium supply line valve mechanism **54A**, the cooling medium release blower **63**, the cooling medium release line **62**, and the cooling medium release line valve mechanism **64A** constitute a rapid cooling unit (RCU) system **1A**.

Next, the controller **51** connected to the temperature sensor **50** is described in detail below.

As described above, the temperature sensor **50** is mounted inside the treating vessel **3** to detect the internal temperature of the vessel **3**. However, the temperature sensor **50** may instead be mounted in the space **33** between the furnace body **5** and the treating vessel **3**, to detect the internal temperature of the vessel **3** indirectly.

The detection signal from the temperature sensor **50** is sent to the controller **51** via the signal line **50a**. The controller **51** reduces a time required for the apparatus to heat up or cool down the treating vessel interior to a predetermined target temperature accurately during heating or cooling or under temperature stability, in a low-temperature region of, for example, 100 to 500° C. FIG. 4 shows a diagram relating to heating/cooling control by the controller **51**.

That is, the controller **51** includes a numerical model **71** relating to predefined heater output and blower output levels, a heater output computing unit **51a** that determines a heater output level based on the numerical model **71** and the furnace internal temperature detected by the temperature sensor **50**, and a blower output computing unit **51b** that determines a blower output level based on the numerical model **71** and the furnace internal temperature detected by the temperature sensor **50**.

The numerical model **71** includes a heater output numerical model **71a** and a blower output numerical model **71b**. The heater output computing unit **51a** determines a heater output level based on the heater output numerical model **71a** and the furnace internal temperature detected by the temperature sensor **50**, and the blower output computing unit **51b** determines a blower output level based on the blower output numerical model **71b** and the furnace internal temperature detected by the temperature sensor **50**.

The heater output numerical model **71a**, part of the numerical model **71**, is described below.

The heater output numerical model **71a** is a mathematical model that can estimate temperature of semiconductor wafers **W** beforehand from the temperature sensor **50** and the heater driving unit **18B** and identify electric power to be supplied to

the heaters **18A** to bring the estimated temperature, as a whole, close to a target temperature. The numerical model **71a** can be any model of a multi-variable, multi-dimensional, or multi-output function type. More specifically, the model disclosed in U.S. Pat. No. 5,517,594, for example, can be used

as the heater output numerical model **71a**. The description given below assumes the use of the model disclosed in U.S. Pat. No. 5,517,594. First, five test-use semiconductor wafers, each with thermocouples mounted centrally on the wafer and at a position 6 mm internally to its edge, are provided in the heat treatment apparatus shown in FIG. 1. Next, the five test-use semiconductor wafers and normal wafers are rested on a boat such that one test-use wafer is positioned in each of five zones. After this, the boat is loaded into the treating vessel. Next, a signal of a high-frequency band and that of a low-frequency band are applied to each heater to acquire temperature sensor output data, on-wafer thermocouple output data (wafer temperature data), heater supply current data, and more, at a sampling period of, for example, 1 to 5 seconds.

After the output data acquisition, temperature bands within a certain temperature range, for example, 400 to 1100° C., are set at intervals of 100° C. (this is to prevent temperatures from being estimated inaccurately if a wide temperature band is covered using one model). The acquired data is then used to establish an auto-regressive exogenous (ARX) model independently for each temperature band. The ARX model is shown in numerical expression 1.

$$y_t + AA_1 y_{t-1} + AA_2 y_{t-2} + \dots + AA_n y_{t-n} = BB_1 u_{t-1} + BB_2 u_{t-2} + \dots + BB_n u_{t-n} + e_t \quad [\text{Numerical expression 1}]$$

$y_t$ : A vector of “p” rows, 1 column, with the following contents at point-in-time “t” as its components.

contents: a variation in the output state of a temperature sensor (since five temperature sensor thermocouples are present in this example, five components), a variation in the output state of the temperature sensor placed at a location different from that of the above (since five temperature sensors are present in this example, five components), a variation in the output state of each thermocouple set up centrally on the wafer (in this example, five components), and a variation in the output state of each thermocouple set up at the edge of the wafer (in this example, five components); in this example, therefore,  $y_1$  denotes a vector of 20 rows, 1 column.

$u_t$ : A vector of “m” rows, 1 column, taking as its components the variation in heater electric power at point-in-time “t” (since five heaters are present in this example, five rows, one column),

$e_t$ : A vector of “m” rows, 1 column, taking white noise as its component.

n: Delay (e.g., 8).

$AA_1$  to  $AA_n$ : Matrix of “p” rows, “p” columns (in this example, 20 rows, 20 columns).

$BB_1$  to  $BB_n$ : Matrix of “p” rows, “m” columns (in this example, 20 rows, 50 columns).

Coefficients  $AA_1$  to  $AA_n$  and  $BB_1$  to  $BB_n$  are determined using the method of least squares or the like.

The ARX model relationship, when applied to a state space method, will have its fundamental equation represented by numerical expression 2.

$$x_{t+1} = Ax_t + Bu_t + K_T e_t$$

$$y_t = Cx_{t+1} + e_t \quad [\text{Numerical expression 2}]$$

where “x” denotes a state variable, K denotes the feedback system of a Kalman filter, and A, B, C each denote a matrix.

In order to improve the treatment rate during actual film formation, the degree is made less dimensional to nearly the 10th order and numerical expression 2 is used to create a numerical model for each temperature band.

In this way, numerical expression 3 for determining the wafer temperature is derived from the inputs (the temperature sensor signals and the heater electric power P) for each temperature band.

$$x_{t+1}^* = Ax_t^* + B(P_{\text{input},t} + u_{\text{bias}}) + L(T_{\text{thermocouple},t} - Cx_t^* + S_{\text{bias}})$$

$$T_{\text{model},t} = Cx_t^* + W_{\text{bias}} \quad [\text{Numerical expression 3}]$$

The test-use wafers are next treated once again, then after this, a comparison is conducted between the wafer temperature,  $T_{\text{mode 1}}$ , estimated from numerical expression 3, and a measured value,  $T_{\text{wafer}}$ , and each created model is tuned. This tuning operation is repeated a plurality of times as required.

Thus obtained is the heater output numerical model **71a** that estimates the wafer temperature appropriately according to the number and layout of wafers to be treated and defines the output level for setting the wafer temperature as a target temperature. Although an example of subjecting the estimated wafer temperature to control has been shown and described, the model may instead be designed to control the observed temperature itself.

As is the case with deriving the numerical model **71a**, the cooling medium supply blower **53** and the cooling medium release blower **63** are actually activated and the temperature of the semiconductor wafers is measured, while the heater **18A** is operated. Thereby, the other blower output numerical model **71b** can be acquired along with the heater output numerical model **71a**.

While the numerical model **71** having both of the heater output numerical model **71a** and the blower output numerical model **71b** has also been shown and described by way of example, the heater output numerical model **71a** and the blower output numerical model **71b** may both be included in a numerical model **71** originally formed of a single element.

The heater output level that the heater output computing unit **51a** has computed is sent to the heater driving unit **18B**, which then drivingly controls the heater element **18** of the heater **18A** on the basis of the heater output level computed by the heater output computing unit **51a**.

Meanwhile, the blower output level that the blower output computing unit **51b** has computed is sent to the inverter driving units **53a**, **63a**, which then drivingly control the cooling medium supply blower **53** and the cooling medium release blower **63**, respectively.

In this manner, the cooling medium supply blower **53** and the cooling medium release blower **63** supply the cooling medium to the space **33** between the furnace body **5** and the treating vessel **3**.

While an example of supplying the cooling medium to the space **33** between the furnace body **5** and the treating vessel **3** by providing the cooling medium supply blower **53** and the cooling medium release blower **63** has been shown and described, the cooling medium may be supplied to the space **33** between the furnace body **5** and the treating vessel **3** by providing only either one of the cooling medium supply blower **53** and the cooling medium release blower **63**. In this case, a closed cooling-medium supply/release line may be formed by connecting both of the cooling medium supply line **52** and the cooling medium release line **62** to the blower. For example, if the cooling medium supply blower **53** only is provided, the inverter driving unit **53a** of the cooling medium

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supply blower **53** will be drivingly controlled according to the blower output level computed by the blower output computing unit **51b**.

Next, operation of the heat treatment apparatus having the configuration shown in FIG. **1** is described below.

First, wafers **W** are mounted in the boat **12** and then this boat is rested on the cylindrical heat-insulating body **11** on the lid **10**. The boat **12** is later loaded into the treating vessel **3** by upward movement of the lid body **10**.

Next, the controller **51** controls the heater driving unit **18B** to activate each heater element **18**, heat the space **33** between the furnace body **5** and the treating vessel **3**, and thus conduct a necessary heat treatment upon the wafers **W** mounted in the boat **12** of the treating vessel **3**.

During the heat treatment, as described below, the space **33** between the furnace body **5** and the treating vessel **3** is forcibly cooled when necessary, to improve efficiency of the heat treatment.

In that case, the controller **51** first activates the cooling medium supply blower **53** and the cooling medium release blower **63**. A cooling medium (20 to 30° C.) is then introduced into the cooling medium supply line **52** and next carried from the cooling medium supply blower **53** to the supply duct **49**.

The cooling medium in the supply duct **49** enters each ring-shaped passageway **38** formed outward with respect to the heat-insulating material **16** of the furnace body **5**. Next, the cooling medium in the ring-shaped passageways **38** is blown off from the cooling medium blowoff holes **40** passed through the heat-insulating material **16**, into the space **33** between the furnace body **5** and the treating vessel **3**, thereby forcibly cooling the space **33**.

The cooling medium in the space **33** is further carried into a heat exchanger **69** through the cooling medium release line **62**, then cooled by the heat exchanger **69**, and released to the outside by the cooling medium release blower **63**.

In this case, the heater output computing unit **51a** determines a heater output level based on the heater output numerical model **71a** and the furnace internal temperature detected by the temperature sensor **50**, and the heater driving unit **18B** drivingly controls the heater **18A** on the basis of the heater output level. In addition, the blower output computing unit **51b** determines a blower output level based on the blower output numerical model **71b** and the furnace internal temperature detected by the temperature sensor **50**, and the inverter driving units **53a**, **63a** conduct driving control of the cooling medium supply blower **53** and the cooling medium release blower **63** by controlling respective rotation speeds of the blowers on the basis of the blower output level.

Thus, the internal temperature of the treating vessel **3** is settled down to the target temperature rapidly and accurately during the heating or cooling phase or stable temperature state in a low-temperature region, for example.

#### Second Embodiment

A second embodiment of the present invention is described below with reference to FIGS. **5** and **6**.

The second embodiment shown in FIGS. **5** and **6** differs only in a configuration of a controller **51**, with substantially all other configurational aspects being substantially the same as in the first embodiment of FIGS. **1** to **4**.

In the second embodiment of FIGS. **5** and **6**, the same elements as in the first embodiment of FIGS. **1** to **4** are each assigned the same reference number or symbol, and detailed description of these elements is omitted.

As shown in FIGS. **5** and **6**, the controller **51** includes a numerical model **71** relating to predetermined heater output and blower output levels, a heater output computing unit **51a**

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that determines a heater output level based on the numerical model **71** and a furnace internal temperature detected by a temperature sensor **50**, and a blower output computing unit **51b** that determines a blower output level based on the numerical model **71** and the furnace internal temperature detected by the temperature sensor **50**.

The numerical model **71** includes a heater output numerical model **71a** and a blower output numerical model **71b**, the heater output computing unit **51a** determines the heater output level based on the numerical model **71a** and the furnace internal temperature detected by the temperature sensor **50**, and the blower output computing unit **51b** determines the blower output level based on the numerical model **71b** and the furnace internal temperature detected by the temperature sensor **50**.

As shown in FIG. **5**, the controller **51** further includes an additional blower output computing unit **51c** that determines an additional blower output level based on a preset blower temperature which follows an exhaust temperature detected by an exhaust temperature sensor **80**.

The blower output level determined by the blower output computing unit **51b**, and the additional blower output level determined by the additional blower output computing unit **51c** are combined by an integrated blower output computing unit **51d**, and on the basis of a blower output level obtained from this combination, the inverter driving units **53a**, **63a** drivingly control the cooling medium supply blower **53** and the cooling medium release blower **63** by controlling respective rotational speeds of the blowers.

Referring to FIGS. **5**, **6**, the heater output computing unit **51a** determines the heater output level based on the heater output numerical model **71a** and the furnace internal temperature detected by the temperature sensor **50**, and the blower output computing unit **51b** determines the blower output level based on the blower output numerical model **71b** and the furnace internal temperature detected by the temperature sensor **50**.

The additional blower output computing unit **51c** determines the additional blower output level appropriate for (based on) the preset temperature following the exhaust temperature detected by the exhaust temperature sensor **80**.

In this case, as shown in FIG. **6**, consider, for example, raising the internal temperature of the furnace by activating a heater **18A** and an RCU system **1A**, and after the furnace internal temperature has reached a certain target temperature, maintaining this target temperature for regulated internal temperature of the furnace.

In FIG. **6**, in addition to the fact that the blower output computing unit **51b** determines the blower output level based on the blower output numerical model **71b** and the furnace internal temperature detected by the temperature sensor **50**, the additional blower output computing unit **51c** determines the temperature preset to follow the exhaust temperature detected by the exhaust temperature sensor **80**, and then determines the additional blower output level based on the preset temperature and the exhaust temperature detected by the exhaust temperature sensor **80**.

The temperature that the additional blower output computing unit **51c** is to set is determined so that the temperature has an appropriate offset value for the exhaust temperature detected by the exhaust temperature sensor **80**. Thus, a minus additional blower output level is always developed. In this way, when the additional blower output computing unit **51c** always generates a minus additional blower output level, the blower output level derived by the integrated blower output computing unit **51d** can be brought close to zero, particularly to stabilize the furnace internal temperature (i.e., to obtain

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temperature stability). During the stabilization of the furnace internal temperature, therefore, the furnace internal temperature can be regulated with the heater 18A only, and thus, use of the RCU system 1A can be minimized.

#### Third Embodiment

A third embodiment of the present invention is next described with reference to FIG. 7.

The third embodiment shown in FIG. 7 differs only in a configuration of a controller 51, with substantially all other configurational aspects being substantially the same as in the first embodiment of FIGS. 1 to 4.

In the third embodiment of FIG. 7, the same elements as in the first embodiment of FIGS. 1 to 4 are each assigned the same reference number or symbol, and detailed description of these elements is omitted.

As shown in FIG. 7, the controller 51 includes a numerical model 71 relating to predetermined heater output and blower output (cooling output) levels, a heater output computing unit 51a that determines a heater output level based on the numerical model 71 and a furnace internal temperature detected by a temperature sensor 50, and a blower output (cooling output) computing unit 51b that determines a blower output (cooling output) level based on the numerical model 71 and the furnace internal temperature detected by the temperature sensor 50.

The numerical model 71 includes a heater output numerical model 71a and a blower output numerical model (cooling output numerical model) 71b, the heater output computing unit 51a determines the heater output level based on the numerical model 71a and the furnace internal temperature detected by the temperature sensor 50, and the blower output computing unit 51b determines the blower output level based on the numerical model 71b and the furnace internal temperature detected by the temperature sensor 50.

The controller 51 additionally includes a flow control computing unit 51e that converts the blower output level determined by the blower output computing unit 51b, into a flow rate of a cooling medium. In this case, the flow control computing unit 51e converts the blower output level into an appropriate flow rate of the cooling medium to be supplied to a space 33 present between a furnace body 5 and a treating vessel 3.

Referring to FIG. 7, the heater output computing unit 51a determines the heater output level based on the heater output numerical model 71a and the furnace internal temperature detected by the temperature sensor 50, and the blower output computing unit 51b determines the blower output level based on the blower output numerical model 71b and the furnace internal temperature detected by the temperature sensor 50.

Furthermore, the flow control computing unit 51e converts the blower output level computed by the blower output computing unit 51b, into a flow rate of the cooling medium and then outputs inverter driving signals based on this flow rate of the cooling medium and on cooling medium flow rates in a cooling medium supply line 52 and a cooling medium release line 62, the flow rates being detected by flow sensors 52a and 62a. After that, based on the inverter driving signals computed by the flow control computing unit 51e, inverter driving units 53a and 63a conduct driving, control of a cooling medium supply blower 53 and a cooling medium release blower 63 by controlling respective rotational speeds. The cooling medium flow rates in the cooling medium supply line 52 and the cooling medium release line 62 are thus controlled.

In this way, the flow control computing unit 51e converts the blower output level computed by the blower output computing unit 51b, into the flow rate of the cooling medium to be supplied to the space 33 between the furnace body 5 and the treating vessel 3, and controls the cooling medium flow rates

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detected by the flow sensors 52a, 62a. Therefore, even if the cooling medium supply line 52 and cooling medium release line 62 of the heat treatment apparatus 1 according to the present embodiment differ from each other in terms of arrangement and/or shape, a desired quantity of cooling medium can be supplied to the space 33 between the furnace body 5 and the treating vessel 3. The differences in arrangement and/or shape between the lines 52, 62, include, for example, a difference in length of the line, and more specifically, apply to the case in which either of the two lines is longer or shorter than the other.

Thus, the internal temperature of the furnace can always be controlled with high accuracy, irrespective of the arrangement and/or shape of the cooling medium supply line 52 and cooling medium release line 62 in the heat treatment apparatus 1.

The above has described an example in which the cooling medium supply blower 53 and the cooling medium release blower 63 are drivingly controlled by controlling the respective rotational speeds on the basis of the cooling medium flow rate computed by the flow control computing unit 51e. It is to be understood, however, that the example does not limit the present invention. That is, a cooling medium supply line valve mechanism 54A may instead be drivingly controlled on the basis of the cooling medium flow rate computed by the flow control computing unit 51e, and a cooling medium release line valve mechanism 64A may be drivingly controlled on the basis of the cooling medium flow rate computed by the flow control computing unit 51e. The above has also described an example in which the flow control computing unit 51e derives the cooling medium flow rate by converting the blower output level and controls the cooling medium flow rates detected by the flow sensors 52a, 62a. However, the control may be conducted using the cooling medium flow rate detected by one of the flow sensors 52a, 62a.

#### Fourth Embodiment

A fourth embodiment of the present invention is next described with reference to FIG. 8.

The fourth embodiment shown in FIG. 8 includes a furnace body 5 partitioned into five zones, 5a, 5b, 5c, 5d, 5e, in that order from above downward, with a heater 18A being provided in each of the zones 5a, 5b, 5c, 5d, 5e.

In addition, RCU systems 1A each including a cooling medium supply line 52 and a cooling medium release line 62 are each connected to each zone 5a, 5b, 5c, 5d, 5e, of the furnace body 5.

Furthermore, a furnace temperature sensor 50 that detects internal temperature or external temperature of a treating vessel 3 is provided for each zone 5a, 5b, 5c, 5d, 5e, of the furnace body 5, and detection signals from the furnace temperature sensors 50 are sent to a controller 51.

The controller 51 regulates the internal temperature of the treating vessel 3 by controlling a cooling medium supply blower 53, and a cooling medium release blower 63, in addition to the heaters 18A in each zone 5a, 5b, 5c, 5d, 5e, of the furnace body 5.

Other apparatus constituent elements in the fourth embodiment of FIG. 8 are substantially the same as those of the first embodiment shown in FIGS. 1 to 4.

In the fourth embodiment of FIG. 8, the same elements as in the first embodiment of FIGS. 1 to 4 are each assigned the same reference number or symbol, and detailed description of these elements is omitted.

The controller 51 in FIG. 8 includes: numerical models 71 relating to predetermined heater output and blower output levels, the models each being for one of the zones 5a, 5b, 5c, 5d, 5e; heater output computing units 51a that each determine

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a heater output level in each zone **5a**, **5b**, **5c**, **5d**, **5e**, based on one of the numerical models **71** and the furnace internal temperature detected by the temperature sensor **50** mounted in each zone **5a**, **5b**, **5c**, **5d**, **5e**; and blower output computing units **51b** that each determine a blower output level in each zone **5a**, **5b**, **5c**, **5d**, **5e**, based on the corresponding numerical model **71** and the furnace internal temperature detected by the temperature sensor **50** mounted in each zone **5a**, **5b**, **5c**, **5d**, **5e**.

Each numerical model **71** includes a heater output numerical model **71a** and a blower output numerical model **71b**, each heater output computing unit **51a** determines the heater output level in each zone **5a**, **5b**, **5c**, **5d**, **5e**, based on the corresponding numerical model **71a** and the furnace internal temperature detected by the corresponding temperature sensor **50**, and each blower output computing unit **51b** determines the blower output level in each zone **5a**, **5b**, **5c**, **5d**, **5e**, based on the corresponding numerical model **71b** and the furnace internal temperature detected by the corresponding temperature sensor **50**.

On the basis of the heater output levels thus determined for each zone **5a**, **5b**, **5c**, **5d**, **5e**, the controller **51** activates heater driving units **18B** to drivingly control the heaters **18A** mounted in the zones **5a**, **5b**, **5c**, **5d**, **5e**. The controller **51** also uses the blower output levels determined for each zone **5a**, **5b**, **5c**, **5d**, **5e** to activate inverter driving units **53a**, **63a** to drivingly control the cooling medium supply blower **53** and the cooling medium release blower **63**, in the RCU systems **1A** provided for the zones **5a**, **5b**, **5c**, **5d**, **5e**, by controlling respective rotating speeds of the blowers.

As described above, in the present embodiment, the inside of the furnace body **5** is partitioned into the zones, **5a**, **5b**, **5c**, **5d**, **5e** and the controller **51** conducts driving control of the cooling medium supply blower **53** and cooling medium release blower **63** in the RCU systems **1A** as well as of the heaters **18A** in the zones **5a**, **5b**, **5c**, **5d**, **5e**. As a result, internal temperatures of the treating vessel **3** in the furnace body **5** are finely controlled for each zone **5a**, **5b**, **5c**, **5d**, **5e**.

What is claimed is:

1. A heat treatment apparatus comprising:

a furnace body;

a heater provided on an inner circumferential surface of the furnace body;

a treating vessel disposed inside the furnace body, the treating vessel forming a space between the furnace body and the vessel and internally accommodating a plurality of objects to be processed;

a blower, connected to the furnace body via a cooling medium supply line, for supplying a cooling medium to the space formed between the furnace body and the treating vessel;

an exhaust pipe connected to the furnace body;

a furnace temperature sensor that detects internal temperature or external temperature of the treating vessel; and

a controller that regulates the internal temperature of the treating vessel by controlling the heater and the blower in order to settle down the internal temperature of the treating vessel to a predetermined target temperature, wherein the controller includes:

a numerical model relating to predetermined heater output and blower output levels;

a heater output computing unit that determines a heater output level based on the numerical model and the furnace internal temperature detected by the furnace temperature sensor; and

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a blower output computing unit that determines a blower output level based on the numerical model and the furnace internal temperature detected by the furnace temperature sensor;

wherein the exhaust pipe includes an exhaust temperature sensor; and

the controller further includes:

an additional blower output computing unit that determines an additional blower output level based on a difference between a preset temperature and an exhaust temperature detected by the exhaust temperature sensor; and

an integrated blower output computing unit that combines the blower output level determined by the blower output computing unit and the additional blower output level determined by the additional blower output computing unit.

2. The heat treatment apparatus according to claim 1,

wherein: the numerical model includes a heater output numerical model and a blower output numerical model; the heater output computing unit determines a heater output level based on the heater output numerical model and the furnace internal temperature detected by the furnace temperature sensor; and

the blower output computing unit determines a blower output level based on the blower output numerical model and the furnace internal temperature detected by the furnace temperature sensor.

3. The heat treatment apparatus according to claim 1,

wherein: the controller further includes a flow control computing unit that converts the blower output level determined by the blower output computing unit, into a flow rate of the cooling medium.

4. The heat treatment apparatus according to claim 3,

wherein: the flow control computing unit controls a rotating speed of the blower based on the flow rate of the cooling medium.

5. A heat treatment apparatus comprising:

a furnace body partitioned into a plurality of zones;

heaters each provided on an inner circumferential surface of each zone of the furnace body;

a treating vessel disposed inside the furnace body, the treating vessel forming a space between the furnace body and the vessel and internally accommodating a plurality of objects to be processed;

blowers, each connected to each zone of the furnace body via a cooling medium supply line, for supplying a cooling medium to the space formed between the furnace body and the treating vessel;

exhaust pipes each connected to each zone of the furnace body;

furnace temperature sensors each provided at a position associated with each zone of the furnace body, each sensor detecting internal temperature or external temperature of the treating vessel; and

a controller that regulates the internal temperature of the treating vessel by controlling the corresponding heater and blower for each zone of the furnace body in order to settle down the internal temperature of the treating vessel to a predetermined target temperature,

wherein the controller includes:

a numerical model for each zone of the furnace body, each numerical model relating to predetermined heater output and blower output levels;

a heater output computing unit that determines a heater output level for each zone, based on the numerical model corresponding to the particular zone and the furnace



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internal temperature detected by the corresponding furnace temperature sensor; and  
 a blower output computing unit that determines a blower output level for each zone, based on the numerical model corresponding to the particular zone and the furnace internal temperature detected by the corresponding furnace temperature sensor;  
 wherein the exhaust pipe includes an exhaust temperature sensor and  
 the controller further includes:  
 an additional blower output computing unit that determines an additional blower output level based on a difference between a preset temperature and an exhaust temperature detected by the exhaust temperature sensor; and  
 an integrated blower output computing unit that combines the blower output level determined by the blower output computing unit and the additional blower output level determined by the additional blower output computing unit.  
 6. A heat treatment apparatus comprising:  
 a furnace body;  
 a heater provided on an inner circumferential surface of the furnace body;  
 a treating vessel disposed inside the furnace body, the treating vessel forming a space between the furnace body and the vessel and internally accommodating a plurality of objects to be processed;  
 a blower, connected to the furnace body via a cooling medium supply line, for supplying a cooling medium to the space formed between the furnace body and the treating vessel;  
 a valve mechanism that regulates a flow rate of the cooling medium supplied from the blower;  
 an exhaust pipe connected to the furnace body;  
 a furnace temperature sensor that detects internal temperature or external temperature of the treating vessel; and  
 a controller that regulates the internal temperature of the treating vessel by controlling the heater and the valve mechanism in order to settle down the internal temperature of the treating vessel to a predetermined target temperature;  
 wherein the controller includes:  
 a numerical model relating to predetermined heater output and cooling output levels;  
 a heater output computing unit that determines a heater output level based on the numerical model and the furnace internal temperature detected by the furnace temperature sensor;  
 a cooling output computing unit that determines a cooling output level based on the numerical model and the furnace internal temperature detected by the furnace temperature sensor; and  
 a flow control computing unit that converts the cooling output level determined by the cooling output computing unit, into the flow rate of the cooling medium, the flow control computing unit controlling the valve mechanism in accordance with the cooling medium flow rate;  
 wherein the exhaust pipe includes an exhaust temperature sensor; and  
 the controller further includes:  
 an additional blower output computing unit that determines an additional blower output level based on a difference between a preset temperature and an exhaust temperature detected by the exhaust temperature sensor; and

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an integrated blower output computing unit that combines the blower output level determined by the blower output computing unit and the additional blower output level determined by the additional blower output computing unit.

7. The heat treatment apparatus according to claim 6, wherein: the numerical model includes a heater output numerical model and a cooling output numerical model;

the heater output computing unit determines a heater output level based on the heater output numerical model and the furnace internal temperature detected by the furnace temperature sensor; and

the cooling output computing unit determines a cooling output level based on the cooling output numerical model and the furnace internal temperature detected by the furnace temperature sensor.

8. A heat treatment apparatus comprising:

a furnace body partitioned into a plurality of zones;

heaters each provided on an inner circumferential surface of each zone of the furnace body;

a treating vessel disposed inside the furnace body, the treating vessel forming a space between the furnace body and the vessel and internally accommodating a plurality of objects to be processed;

blowers, each connected to each zone of the furnace body via a cooling medium supply line, for supplying a cooling medium to the space formed between the furnace body and the treating vessel;

a valve mechanism that regulates a flow rate of the cooling medium supplied from each blower;

exhaust pipes each connected to each zone of the furnace body;

furnace temperature sensors each provided at a position associated with each zone of the furnace body, each sensor detecting internal temperature or external temperature of the treating vessel; and

a controller that regulates the internal temperature of the treating vessel by controlling the corresponding heater and valve mechanism for each zone of the furnace in order to settle down the internal temperature of the treating vessel to a predetermined target temperature,

wherein the controller includes:

a numerical model for each zone of the furnace body, each numerical model relating to predetermined heater output and cooling output levels;

a heater output computing unit that determines a heater output level for each zone, based on the numerical model corresponding to the particular zone and the furnace internal temperature detected by the corresponding furnace temperature sensor;

a cooling output computing unit that determines a cooling output level for each zone, based on the numerical model corresponding to the particular zone and the furnace internal temperature detected by the corresponding furnace temperature sensor; and

a flow control computing unit that converts the cooling output level determined by the cooling output computing unit for each zone, into the flow rate of the cooling medium, the flow control computing unit controlling the valve mechanism corresponding to the particular zone in accordance with the cooling medium flow rate;

wherein the exhaust pipe includes an exhaust temperature sensor; and

the controller further includes:

an additional blower output computing unit that determines an additional blower output level based on a dif-

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ference between a preset temperature and an exhaust  
temperature detected by the exhaust temperature sensor;  
and  
an integrated blower output computing unit that combines  
the blower output level determined by the blower output  
computing unit and the additional blower output level  
determined by the additional blower output computing  
unit.

\* \* \* \* \*

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